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Measurement and statistic analysis of combustion heat of two kinds of household spray aerosols in China

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Abstract

High volatility makes it difficult to measure the combustion heat of spray aerosols' content. However, calorific value is a precondition to grade the fire hazard classification of aerosol products according to UN Recommendations of the Transport of Dangerous Goods - Model Regulations. With auxiliary of empty medical capsule, injector and adhesive tape, etc., a series of combustion heat tests on some household aerosol products including insecticide aerosol and air freshener aerosol products sold in China were completed with a commercial oxygen bomb calorimeter. The confidence interval of different kinds of aerosols' combustion heats were researched at 95% confidence level. The results show that the confidence interval range of combustion heat of insecticide aerosol is from 43359 J/g to 49911 J/g, higher than 20 kJ/g, which is the critical quota to determine the flammability of aerosol products. The heat of air freshener aerosols are less than one-tenth of insecticide aerosols, which is from 2743 J/g to 3430 J/g. According to the UN regulation, insecticide aerosol products at least belong to the flammable ones at 95% confidence level, and the air freshener aerosol products are relatively safe on the characteristic of fire risk.

Keywords: insecticide aerosol; air freshener aerosol; combustion heat; oxygen bomb calorimeter; flammable

Nomenclature

m	mass of aerosol content in capsule (g)
n	numbers of tests
Q	net heat of combustion at room temperature and normal pressure (J/g)
Q_{total}	total heat of combustion measured with oxygen bomb calorimeter at room temperature and normal pressure (J)
$Q_{\text{capsule \& tape}}$	heat of capsule and tape combustion at room temperature and normal pressure (measured in advance, 2562 J)
$Q_{\text{ignition thread and wire}}$	heat of ignition thread and wire combustion at room temperature and normal pressure (measured in advance, 150 J)
$\overline{Q}$	average combustion heats on a same type of product
$\hat{Q}$	average $\overline{Q}$ on a same kind of aerosol products
X_i	measured combustion heat in number No. i test
$\overline{X}$	average value of a sample's measured combustion heats

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μ	assumed average value of a sample's combustion heats
$\sigma_0^{\ 2}$	assumed standard deviation of a sample

1. Introduction

The fire and explosion disasters caused by aerosol products occurred ever and again in the world. A typical example was in September of 2009, a aerosol product explosion broken a door of an apartment to pieces in GuiGang, GuangXi province of China [1]. Another example could be found in June, 2010, two insecticide aerosol explosions consecutively, one led to a girl's face injured and the other lead to roof rupture [2]. According to a research report [3], there are about 1000 manufacturers with more than 800 million cans of aerosol product in china in 2007. In addition, the aerosol products consumption will have a further growth with the economic growth in China. Huge potential production will increase the probability of fire and explosion. Similarly, fire and explosion risks is threat to the family safety in other country [4]. A 41-year-old woman was killed by the explosion of air freshen spray's fire in a kitchen [5]. It is important to grade the aerosol products' fire classification. As a result, good management practices and rules could be work out for safety.

Calorific measure is a precondition to grade the fire hazard for aerosol products according to UN Recommendations of the Transport of Dangerous Goods - Model Regulations. There are many literatures on calorific measure. Stephen M. Akers [6] measured the heat of combustion of biodiesel and petro diesel. D.Peralta [7] researched the combustion performance of coal samples and their blends with a commercial bomb calorimeter. However, most of the literatures are focus on solids, or low volatility liquids, or the mixtures of them. Aerosol contents contain solvent components and aerosol gases that made them volatile. In this paper, combustion heat experiments were conducted by a commercial oxygen bomb calorimeter with auxiliary of empty medical capsule, injector and adhesive type, etc. And, the statistic analyses of the heats of volatile household aerosol products were studied.

2. Materials and method

2.1. Materials

Two kinds of household aerosol products sold in China were used in these experiments: insecticide aerosol products and air freshener aerosol products. There are several types' products for one kind of aerosol. For example, several types of aerosol products, such as Radar® insecticide aerosol (Citrus Flavor), Invincible® insecticide aerosol (No Fragrance), and Invincible® Mosquito-killing aerosol, etc., belong to the insecticide aerosol kind.

Aerosol products used in these experiments were listed in Table 1.

Table 1. Aerosol products used in experiments

Aerosol products kind	Different types of products of same kind
Insecticide aerosol	Radar® insecticide aerosol (Citrus Flavor),
	Invincible® Mosquito-killing aerosol (Fragrance Type),
	Invincible® insecticide aerosol (No Fragrance Type),
	Gunner® insecticide aerosol.
Air freshener aerosol	XiLan® air freshener aerosol (Lemon Flavor),
	JiaLi® air freshener aerosol (Rose Flavor),
	JiaLi® air freshener aerosol (Lavender Flavor),
	JiaAn® air freshener aerosol (Wormwood Leaf Flavor),
	BeiJieJia® air freshener aerosol (Jasmine Flavor).

2.2. Method

The combustion heats of volatile liquids are more difficult to be measured than solids and other liquids with an oxygen bomb calorimeter. Most spray aerosols are driven by combustible gases. The combustible gas of an aerosol product will evaporate rapidly when it is spraying into a crucible of oxygen bomb calorimeter directly. And, it is not easy to spray the aerosol content into a medical capsule with the method which the IEC standard [8] recommended. Pulled out the rod and piston of an injector which is made of glass, sprayed the aerosol content into the cylinder of the injector. Then the aerosol content was transferred into a capsule easily by injection. At last, sealed the capsule immediately with 3 cm×1 cm adhesive tape prepared in advance.

The empty capsule and adhesive tape was weighted on a four decimal laboratory scale. Aerosol content mass added into the capsule is the increased weight. The capsule with aerosol content was put into oxygen bomb, pressurized to 3.5 atm. The test was conducted at room temperature. The most common household spray aerosol products include insecticide aerosols and air freshener aerosols were chosen for the test. The ignition heats were measured with a commercial oxygen bomb calorimeter.

3. Results and discussion

3.1. Analysis on test results of single aerosol product

The net combustion heat of aerosol ignition is represented by symbol Q, which is related to the total heat measured with oxygen bomb calorimeter, the combustion heat of the capsule, and the heat of ignition thread and wire, as was shown in equation (1).

$$Q = (Q_{\text{total}} - Q_{\text{capsule \& tape}} - Q_{\text{ignition thread and wire}})/m \tag{1}$$

The specific combustion heats, obtained from seven combustion experiments on Radar insecticide aerosol (citrus flavor) were shown in Table 2. The values of Q corresponding to the results were calculated with equation (1).

Table 2. Test on combustion heat of Radar insecticide aerosol (citrus flavor)

NO.	*m* (g)	*Q*（J/g）
1	0.1112	50053
2	0.2268	46238
3	0.1864	48134
4	0.2145	47015
5	0.1917	47858
6	0.2306	46437
7	0.1305	49315

Assuming that combustion heats of an aerosol content obtained from different experiments are normally distributed as $N(\mu, \sigma_0^2)$. The estimation of the average value of the combustion heats $\overline{X}$ is assumed to be μ. Then, $\overline{X}$ obeys the law of normal distribution $N(\mu, \frac{\sigma_0^2}{n})$. Then

$$\mathrm{U} = \frac{\overline{X} - \mu}{\frac{\sigma_0}{\sqrt{n}}} \tag{2}$$

U obeys the law of normal distribution $N(0,1)$.

The confidence level is set to be 95%. In the range of probability $1-\alpha=0.95$, there must exist a $\mathrm{u}_{\frac{\alpha}{2}}$, meeting the equation (3)

$$\mathrm{P}\left\{ |\mathrm{U}| < \mathrm{u}_{\frac{\alpha}{2}} \right\} = 1 - \alpha \tag{3}$$

Then

Lower limit of confidence interval:

$$\overline{X} - \mathrm{u}_{\frac{\alpha}{2}} \frac{S}{\sqrt{n}} \tag{4}$$

Upper limit of confidence interval:

$$\overline{X}+u_{\frac{a}{2}}\frac{S}{\sqrt{n}} \tag{5}$$

Where
$\overline{X}$ = 47864 J/g;
$u_{\frac{a}{2}}$ =1.96;
n=7.

$$S=\sqrt{\frac{\sum_{i=1}^{4}(X_i-\overline{X})^2}{n-1}}=1435.912$$

The range of the confidence interval is (46800, 48928).

If table footnotes should be used, place footnotes to tables below the table body and indicate them with superscript lowercase letters. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article.

3.2. Analysis of test results of different aerosol products of same kind

Main flammable components of same kind aerosol products are mostly similar, except some auxiliary components, the calorimetric test can be grouped by the aerosol product kinds. From the aerosol content mass and the combustion heat of different experiments, the average combustion heat and the confidence interval of same type aerosol products were derived. The results of insecticide aerosol products were given in Table 3.

Table 3. Average combustion heat and confidence interval of different insecticide aerosol products

Variety insecticide aerosol products	$\overline{Q}$ (J/g)	Confidence interval (J/g)
Radar® insecticide aerosol（Citrus Flavor）	47864	（46800, 48928）
Invincible® Mosquito-killing aerosol（Fragrance Type）	48339	（46767, 49911）
Insecticide® aerosol（No Fragrance Type）	46213	（44422, 48004）
Gunner® insecticide aerosol	45056	（43359, 46753）

Note: Confidence interval is corresponding to 95% of confidence level.

3.3. Analysis of test results of different kinds of aerosol products

Insecticide aerosol and air freshener aerosol were researched and the tests results are given in Table 4.

Table 4. Average combustion heat and confidence interval range of different kinds of aerosols

Aerosol products kinds	$\hat{Q}$ (J/g)	Confidence interval range (J/g)
Insecticide aerosol	46868	(43359, 49911)
Air freshener aerosol	3087	(2743, 3430)

Note: Confidence interval range is the union of the confidence intervals of different aerosol products of the same kind.

For an aerosol product whose combustion heat is unclear, the confidence interval range of combustion heats is a good reference, because for most aerosol products, the main components of a same kind are similar. This is a helpful method for determining the flammability of the aerosol products.

20 kJ/g is the critical quota to determine whether the aerosol product is a flammable one or extremely flammable one with the supports of ignition distance test according to the *UN Recommendations on the Transport of Dangerous Goods - Model Regulations.* If combustion heat of an aerosol product is higher than 20kJ/g, it belong to flammable ones at least. According to this principle, whether the combustion heat is 43359 kJ (even lower) or 49911 kJ/g, as shown in Table 4, it will not affect the flammability of the insecticide aerosol products at 95% confidence level, as previously calculation. Air freshener aerosol products are relatively safe according to the analysis.

4. Conclusions

Combustion heat of two kinds of common household aerosol products, include Insecticide aerosol and air freshener aerosol, were tested with a commercial oxygen bomb calorimeter, with auxiliary of empty medical capsule, injector and adhesive tape, etc. Statistic analyses were completed based on the data of the calorimetry experiments. Insecticide aerosol products are at least flammable, even extremely flammable ones according to the UN regulations, and air freshener aerosol products are relatively safe.

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